

ESTIMATING THE HEALTH HAZARD COSTS OF ARMY MATERIEL: A METHOD FOR HELPING PROGRAM MANAGERS MAKE INFORMED HEALTH RISK DECISIONS

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We have developed a model to assist the U.S. Army estimate weapon system health hazard costs based on the probability of a hazard occurring and the severity of that hazard. We linked health hazard categories to types of clinic services that might be required as a result of exposure to a specific health hazard; and diagnostic categories based on the potential medical effects that could occur as a result of exposure to a specific health hazard. We researched incidence rates and calculated costs based on industry-wide data on injuries, lost time, hospitalization, and disability, and this framework provides a method to reasonably estimate the medical and lost military manpower costs of unabated health hazards associated with Army materiel. Using the outputs of the model will increase the effectiveness of health risk assessment and management, and better enable the Army to eliminate or control materiel health hazards and control life-cycle costs. Application of this model to other prevention disciplines in acquisition and preventive medicine will provide decision makers with invaluable quantitative information regarding cost avoidance.

U.S. Army medical personnel currently conduct health hazard assessments of new or improved materiel. They assess the types of hazards that exist; the injuries or illnesses likely to result from them; the level of health risk for each hazard; and the corrective actions

needed to eliminate or abate the hazard. Health hazard assessment reports provide this information to the materiel program managers.

We have developed a framework for a medical cost avoidance model (MCAM) that provides a method to quantify reason-

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able estimates of the medical and lost time costs associated with unabated Army materiel health hazards. Use of the model will increase the effectiveness of health risk assessment and management.

It seems intuitive that health hazard intervention and prevention activities should significantly ease the burden on the health care system by reducing deaths, disabilities, lost time away from the work site, hospitalization, clinical medical costs, injuries and illnesses, and rehabilitation costs. For years, however, the preventive medicine community has needed a way to estimate the costs avoided—a critical step in the prevention process. Given the cost-conscious environment in which program managers make their decisions, the need to quantify health hazard costs is essential.

We developed this, the first version of the MCAM, specifically to help the U.S.

Army estimate the health hazard costs of materiel systems. It quantifies these costs based on the probability of a hazard and its severity. We linked health hazard categories to potential types of clinic services that might be required as a result of exposure to a specific health hazard, and diagnostic categories based on the potential medical effects that could occur as a result of exposure to a specific health hazard. We then used this information to determine incidence, distribution, and other rates for injury, clinic visits, hospitalization, lost time, disability, rehabilitation, and death. The result is a model that quantifies expected costs of a health hazard. This model better describes a stated health risk, associated lost military manpower, and monetary impact if no preventive or corrective actions occur. We do not address other technical or programmatic risks that materiel program managers must face.

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We are presenting the model to stimulate thought and feedback; it can and should be further refined. Based on our model, Army health hazard assessment reports have recently begun to include the medical costs for injuries or illnesses that will result from the hazards. This information allows materiel program managers to understand the medical costs associated with their systems, and in turn make informed tradeoff decisions concerning corrective actions. The model is currently available as a personal computer-based tool that can perform cost calculations based on user input.

As use of the MCAM continues to increase, and follow-up data become available, we can develop more accurate cost distribution factors, resulting in more accurate forecasts of health costs.

HEALTH HAZARD ASSESSMENTS

The Army performs health hazard assessments in all phases of the acquisition process. Eliminating or controlling hazards early in the process will reduce abatement costs. The Army assesses materiel health hazards using a risk assessment code (RAC) matrix that is defined in Army Regulation 40-10, "Health Hazard Assessment Program in Support of the Army Materiel Acquisition Decision Process," Oct. 1, 1991. This matrix is similar to the ones described in Army Regulation 385-16, "System Safety Engineering and Management," Field Manual 101-5, "Staff Organization and Operations," and Department of Defense (DoD) Instruction 6055.1, "DoD Occupational Safety and Health Program." DoD has been using this

risk-based method to prioritize installation safety and health hazards for abatement since the early 1980s.

ASSESSING HEALTH RISK

Risk per se is a probability statement. The term "health risk," however, combines the severity of a hazard's potential consequences and probability of exposure to the hazard.

Before assigning a health risk to a particular piece of equipment or materiel system, Army evaluators first determine the potential hazards operators face. In their evaluation they also consider existing control measures to minimize exposure to the hazards. Next, they assign each hazard a relative level of risk. The model we present here incorporates the DoD method for assigning "health risk," which combines a hazard's severity and probability. Hazard severity is a relative score that reflects the magnitude of exposure to physical, chemical, or biological hazards and the severity of the medical effects caused by exposure to the hazard. Hazard probability is a relative score that reflects the duration of the exposure and the number of people per system exposed to the hazard. The hazard severity and hazard probability categories are shown in Table 1.

The risk assessment code resulting from the combination of these two components can range from 1 (very high health risk) to 5 (very low health risk). For example, a hazard of marginal severity (hazard severity = III) with an exposure assessed as probable (hazard probability = B) has a moderate overall risk (RAC = 3).

MEASURING COSTS

To quantify the two components of this risk assessment score, hazard severity (S_k) and hazard probability (P_e), for use as cost drivers in our model, we developed a value for each severity and probability category based on the subjective interpretation of the written category descriptions in the regulations. These values are shown in Table 1 in parentheses.

To measure total medical costs for a particular system, assessors must know the number of systems (N_s) that will be procured or are in the inventory and the number of soldiers or crew size per system (N_{ps}). Because the Army uses this matrix for determining system health risk, our intent was to quantify the costs associated with each RAC. Table 1 presents, for a hazard in a sample system—the number of systems (N_s) = 7400 and the number of soldiers per system (N_{ps}) = 4.—the total costs the Army will incur as a result of not abating the hazard for each RAC in the matrix. For example, we can see that

if a hazard assessor assigned a hazard severity of I and a hazard probability of A, the resulting RAC 1 relates to a total cost incurred of \$15,088,000 per year. Program managers can make better tradeoff health risk decisions knowing the dollar impact in addition to RACs. Our procedure for calculating cost is the focus of this article.

Often it is not possible to eliminate a health hazard, even by appropriate controls. Even with a controlled hazard there is a health risk. This residual risk is what remains after controlling a health hazard. One can determine avoided costs by subtracting the residual cost of a hazard from its unabated cost. For example, with a hazard assigned a hazard severity of I and a hazard probability of A, the resulting RAC 1 relates to a total cost incurred of \$15,088,000 per year. If design changes result in a hazard severity of III and a hazard probability of A, the resulting RAC 2 (residual risk) relates to a total cost incurred of \$137,000. The avoided costs therefore are \$15,088,000 minus \$137,000 equals \$14,951,000 per year.

Table 1.
Risk Assessment Codes (RAC) and Costs (Thousands of Dollars) Matrix

Hazard Severity (S_k)	Hazard Probability (P_e)				
	Frequent	Probable	Occasional	Remote	Improbable
	A (.9)	B (.5)	C (.2)	D (.01)	E (.001)
I (1) Catastrophic	1 (\$15,088)	1 (\$8,471)	1 (\$3,508)	2 (\$365)	3 (\$216)
II (.1) Critical	1 (\$1,410)	1 (\$783)	2 (\$313)	3 (\$16)	4 (\$1)
III (.01) Marginal	2 (\$137)	3 (\$76)	3 (\$30)	4 (\$2)	5 (\$0.152)
IV (.001) Negligible	3 (\$13)	5 (\$7)	5 (\$3)	5 (\$0.148)	5 (\$0.015)
Notes: The calculations are based on a high risk system. The numbers 1, 2, 3, 4, and 5, in the columns under Hazard Probability are the RACs. The numbers in parentheses in the columns under Hazard Probability are the medical costs that are incurred for a given RAC if no intervention occurs.					

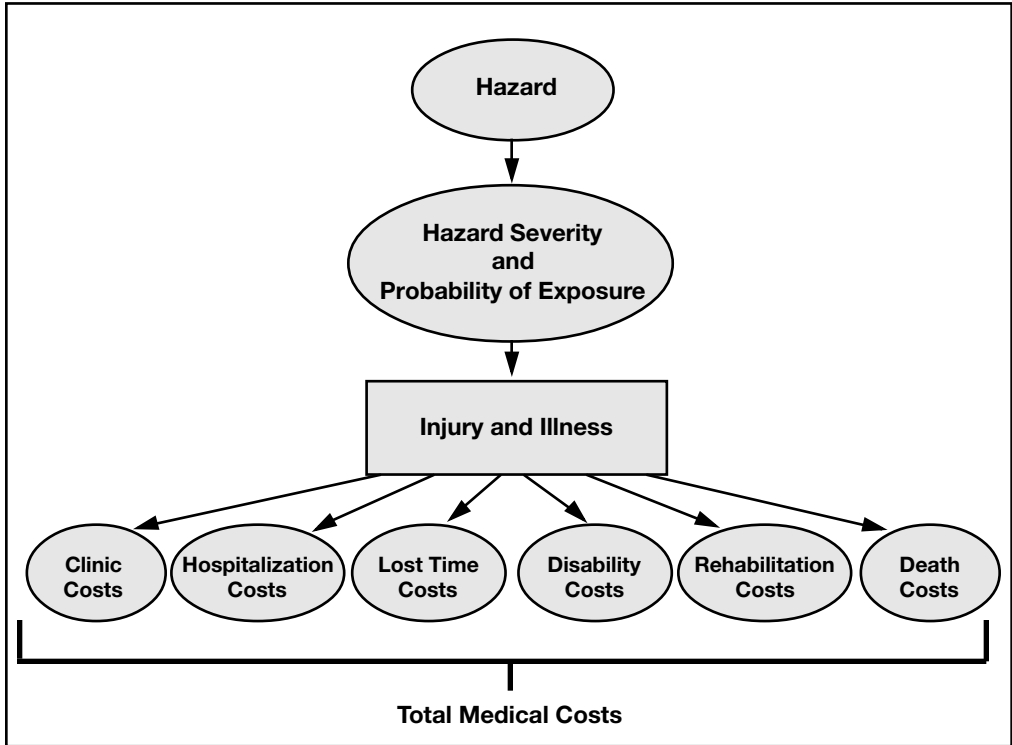


Figure 1. Cost Components for a Single Hazard

METHODS

THE COST MODEL FRAMEWORK

We developed the framework in Figure 1 for determining costs based on six cost components that result from exposure to hazards that cause illness, injury, or death.

Six basic events can occur when a soldier becomes ill or injured. He or she may:

- visit a medical clinic for basic outpatient treatment, medication, and tests (clinic costs, C_c);
- visit a hospital for inpatient observation, emergency or definitive treatment, and more detailed tests (hospitalization costs, C_h);
- lose time away from the job due to clinic and hospital appointments, assignment to quarters, and inability to perform on the job (lost time costs, C_l);
- experience disability, either immediately while on active duty or at a later date after discharge or retirement (disability costs, C_{di});
- require rehabilitation because of disability (rehabilitation costs, C_r); and
- suffer death as a result of exposure severity or complications (death costs, C_{de}).

Because of funding constraints, this initial version of the MCAM did not in-

corporate the costs to acquire and train personnel replacements for those soldiers injured, ill, or killed. We also did not incorporate performance degradation costs or the nonmonetary effect on readiness. Nor did we incorporate the costs related to the impact on family quality of life. These costs could be substantial and should be considered by the system program manager. We recognize that these costs may vary greatly; for example, it costs more to train a pilot than an Infantryman. We believe the system program manager is in the best position to judge the magnitude and impact of these additional costs.

We used industry-wide incidence rates, distribution factors, and other rates for injury, hospitalization, lost time, disability, rehabilitation, and death to quantify health hazard costs for each of the six cost components. The model estimates the total cost per year for exposures to hazards that result in illness, injury, or death, and can be expressed in equation form as follows:

$$\begin{aligned} \text{Hazard costs/year} = & \\ & \text{clinic costs/year} + \text{hospitalization} \\ & \text{costs/year} + \text{lost time costs/year} \\ & + \text{disability costs/year} + \text{rehabili-} \\ & \text{tation costs/year} + \text{death costs/} \\ & \text{year.} \end{aligned}$$

ASSUMPTIONS

We made two primary assumptions: The first was that we could establish the incidence rates—the rate of injury or illness in a group over a period of time—based on historical industry-wide data. Second, we assumed that a medical assessor conducted the risk assessment properly.

We developed incidence rates from comparable industry-wide data that were available during model development, because not all the required data were available or accessible via military sources. This required that we extrapolate from private industry data and relate it to military systems. The risk assessment codes used in this article were determined by experienced health hazard assessors. The assignment of a RAC, with its associated hazard probability and hazard severity, is the critical element in communicating health risk to program managers. Incorrect assessments may result in inaccurate cost modeling.

HAZARD SEVERITY AND HAZARD PROBABILITY

Because we could not use the severity and probability categories in their descriptive form, we developed numerical values for them. These hazard severity (S_k) and hazard probability (P_e) values were key factors in using the model and provided for a range of medical cost and outcome values. We obtained consensus on the values from practicing health hazard assessment experts from the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM).

HEALTH HAZARD LINK

Next, we linked each of the nine health hazard categories (Figure 2) to potential types of clinic services that might be required as a result of exposure to a specific health hazard; and diagnostic categories based on the potential medical effects that could occur as a result of exposure to a specific health hazard. We obtained data on the types of clinic services from the *Federal Register*, and hospitalization, lost time, and disability diagnostic data from

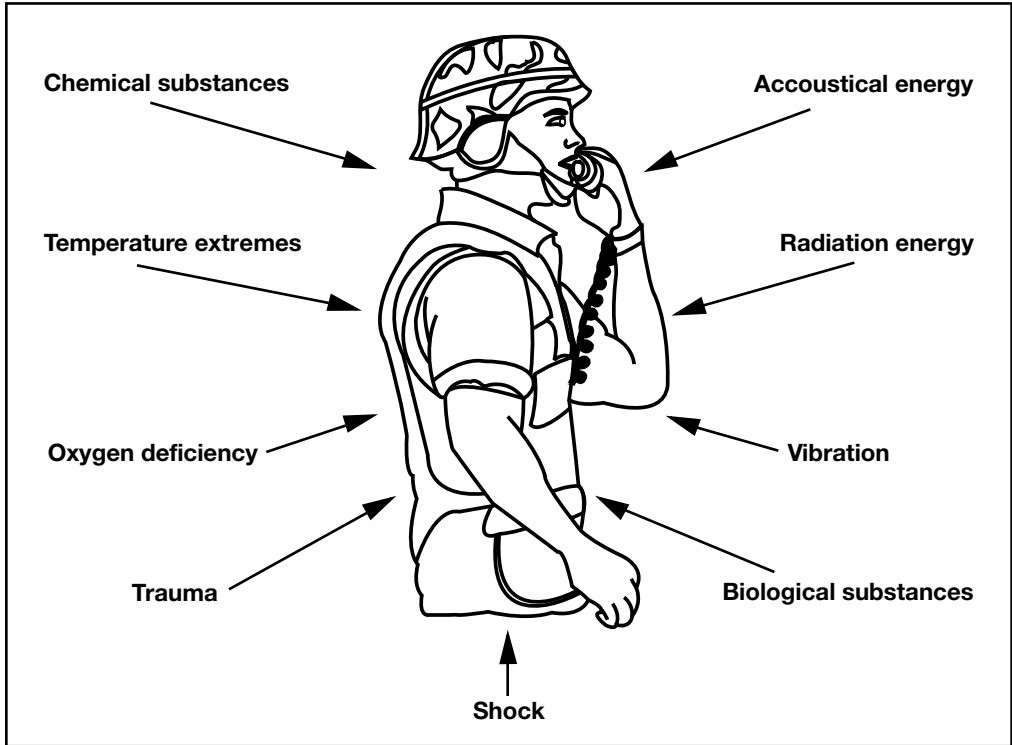


Figure 2.
Army Health Hazard Categories Encountered with Army Materiel

the Army, the Department of Labor, and the Department of Veterans Affairs, respectively.

There are nine Army health hazard categories. Exposure to an individual hazard in one of these categories can result in a variety of injury and illness. The classification (coding) of injury and illness varies. This is because almost every national data collection agency codes injury or illness descriptions differently. For example, the data we used classified:

- hospitalization medical diagnoses using the *International Classification of Disease* (9th revision) (ICD-9) diagnosis categories;

- lost time diagnoses using the Bureau of Labor Statistics Occupational Injury and Illness Classification System; and
- disability diagnoses using the Department of Veterans Affairs Disability Classification System.

An exposure to a chemical substance health hazard could result in a:

- visit to an “emergency care” clinic;
- hospitalization diagnosis of disease of the respiratory system;
- lost time diagnosis of exposure to caustic, noxious, or allergic substances; and

- disability diagnosis affecting the lungs and pleura.

While these diagnostic category classifications may not be comparable between data sets; this did not present a problem in determining medical costs, because we calculate costs using the appropriate data set for each cost component.

RISK LEVEL LINK

We then correlated the industry categories of high, medium, and low health risk with Army system categories. This would allow us to use representative industry data for evaluating materiel health hazards.

We used 1993 data from the Bureau of Labor Statistics representative of the range of illness and injury rates within the Army. We selected industries with a high, medium, and low incidence of illness and injury. For example:

- The construction industry represents high health-risk occupations (12.2 injuries or illnesses per 100 full-time workers per year).
- The transportation industry represents occupations with medium health risk (9.5 injuries or illnesses per 100 full-time workers per year).
- The service industry represents occupations with low health risk (6.7 injuries or illnesses per 100 full-time workers per year).

We analyzed each of the categories of military systems to determine the appropriate industry illness and injury incidence rate to apply to each system category. We based our analysis on limited Army illness

and injury data and the experience of a group of senior medical health risk assessors who had worked with these systems. Table 2 shows the correlation between the system categories, industry categories, and incidence (health risk) levels—high, medium, or low—we used to estimate the model component costs.

DETERMINING COSTS

We developed equations for estimating costs that incorporated hazard severity and probability of exposure to the hazard (Table 3). Table 4 provides the equation variables and their values along with a brief description. The equations include costs per year for clinic services, hospitalization, lost time, disability, rehabilitation, and death.

We used industry-wide incidence rates, distribution factors, and other rates for injury, lost time, hospitalization, disability, rehabilitation, and death to quantify health hazard costs based on the six cost components—our model framework—to estimate the costs of exposure to hazards. Below we describe the calculation of each of the cost components.

Clinic costs (C_c). Our primary source of illness and injury data was the *U.S. Department of Labor Bureau of Labor Statistics Survey on U.S. Occupational Injuries and Illnesses for 1993*, December 1994. We selected incidence of illness and injury data from the Bureau of Labor Statistics data representative of the range of illness and injury rates within the Army. We selected the industry categories with a high, medium, and low incidence of illness and injury as previously discussed.

We analyzed each of the categories of materiel systems to determine the appropriate illness and injury incidence rate (I_i)

Table 2.
Correspondence of Risk Levels for Industries and Materiel Systems

System category	Industry category	Assigned risk level
Armored fighting vehicles	Construction	High
Engineer and logistics equipment	Construction	High
Missile artillery	Construction	High
Tube artillery	Construction	High
Air defense systems	Transportation	Medium
Aircraft technology and armament	Transportation	Medium
Ground antitank weapons	Transportation	Medium
Infantry weapons	Transportation	Medium
Other	Transportation	Medium
Smokes and obscurants	Transportation	Medium
Chemical defense equipment	Service	Low
Clothing and individual equipment	Service	Low
Communications, command, and control	Service	Low
Surveillance, fire control, and electronic warfare	Service	Low
Training devices	Service	Low

to apply to each system category. Additionally, we queried historical health hazard assessment data to determine the number of hazards and their RACs for each system category. We rank ordered the system categories using a RAC weighted comparison technique. We based our analysis on limited Army illness and injury data and the experience of a group of senior medical health risk assessors who had worked with these systems. The selected incidence (health risk) levels—high, medium, or low—are used to estimate the model component costs. These values are listed in Table 5.

We developed the values for the number of clinic visits (N_c) by injured or ill soldiers based on the seriousness of the medical effects that could occur. As the severity of the medical effects increases the number of clinic visits would be expected to increase. We subjectively deter-

mined the values based on a consensus of internal and external panel of subject matter experts. The values we selected for each hazard severity category are listed in Table 6.

Hospitalization costs (C_h). Our primary sources for hospitalization data were the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) *Medical Surveillance Monthly Report*, April 1995, and “CHAMPUS DRG Weights for Fiscal Year 1996” published in the *Federal Register*.

We correlated selected classifications of illness or injury diagnoses with the categories of health hazards, as previously discussed. We considered these data representative of the range of hospitalization rates within the Army for hazards associated with weapon systems. We then calculated incidences of hospitalization (I_h)

Table 3. Cost Component Equations

Related Cost Component	Component calculation	Equation
All (except death costs)	Number of people exposed to hazard	$N_e = P_e \times N_s \times N_{ps}$
Clinic costs	Number of people injured or ill	$N_i = N_e \times S_k \times I_i$
Clinic costs	Clinic costs	$C_c = N_v \times F_c$
Clinic costs	Number of clinic visits	$N_v = N_e \times S_k \times [V_e + (I_i \times N_c)]$
Hospitalization costs	Hospitalization costs	$C_h = N_h \times F_h$
Hospitalization costs	Number of persons hospitalized	$N_{ph} = N_e \times S_k \times I_h$
Hospitalization costs	Number of hospital days	$N_h = N_e \times S_k \times I_h \times \sum (D_{hd} \times D_{ho})$
Lost time costs	Lost time costs	$C_l = N_l \times W_d \times B_f$
Lost time costs	Number of persons losing time	$N_{pl} = N_e \times S_k \times I_l$
Lost time costs	Number of lost workdays	$N_l = N_e \times S_k \times I_h \times \sum (D_{ld} \times D_{lt})$
Disability costs	Disability costs	$C_{di} = N_e \times S_k \times I_v \times T_v \times \sum (D_v \times B_v) \times 12 \text{ mo/yr} + [(I_t \times B_t) + (I_p \times B_p)]$
Disability costs	Number of persons disabled	$N_{pd} = N_e \times S_k \times (T_v \times I_v + I_t + I_p)$
Rehabilitation costs	Rehabilitation costs	$C_r = N_e \times S_k \times I_v \times T_v \times \sum D_r \times Q_r \times B_r$
Rehabilitation costs	Number of rehabilitation cases	$N_r = N_e \times S_k \times I_v \times T_v \times \sum D_r \times Q_r$
Death costs	Death costs	$C_{de} = (N_{de} \times B_{de})$
Note: Number of people exposed to hazard ($N_e = P_e \times N_s \times N_{ps}$) is a common term related to all cost components except death costs.		

Table 4. Equation Variables

Related cost component	Equation variable	Variable value	Description
All (except death costs)	P_e	See Table 1	Hazard Probability (HP) - Probability of exposure per year, based on the determined hazard probability category
All (except death costs)	S_k	See Table 1	Hazard Severity (HS) factor based on the determined hazard severity category
All (except death costs)	N_s	No. of systems	Number of systems, the total number individual items of materiel, equipment, or weapon systems in Army inventory
All (except death costs)	N_{ps}	No. of persons	Number of persons per system, or crew size for system, or item
All (except death costs)	N_e	Calculated	Total number of people exposed to hazard per year for the systems or items
Clinic costs	C_c	Calculated	Cost of clinic visits
Clinic costs	N_i	Calculated	Number of people injured or ill
Clinic costs	N_v	Calculated	Number of clinic visits
Clinic costs	V_e	0.75	Visit constant as result of exposure. The visit constant (V_e) equals 0.75 and is based on exposure to a health hazard that results in illness or injury. We assumed that if an exposure event occurs, then 75 percent of all persons exposed to the hazard will visit the clinic for an examination to determine whether any injury has occurred.
Clinic costs	I_i	See Table 5	Incidence of injury or illness based on the determined risk level for the individual item of materiel
Clinic costs	N_c	See Table 6	Number of visits by injured or ill personnel based on the determined hazard severity category. The hazard severity category determines the seriousness of the medical outcomes that could occur. As the severity increases, the number of clinic visits increases. For this cost component, based on values selected by a panel of experts, we assigned the number of visits based on the hazard severity category and the potential medical outcomes.
Clinic costs	F_c	\$122 per visit	Average fee per clinic visit, based on the average of various types of clinic service visit fees. We found the average fee was \$122 per clinic visit.

Table 4. Equation Variables (continued)

Hospitalization costs	C_h	Calculated	Cost of hospitalization
Hospitalization costs	N_{ph}	Calculated	Number of persons hospitalized
Hospitalization costs	N_h	Calculated	Number of hospital days
Hospitalization costs	I_h	See Table 7	Incidence of hospitalization based on the determined risk level for the individual item of materiel
Hospitalization costs	D_{hd}	See Table 8	Factor for the average number of days in hospital per person based on historical hospital stay distribution
Hospitalization costs	D_{ho}	See Table 9	Factor for the hospitalization population distribution for average number of days in hospital
Hospitalization costs	F_h	\$1,669 per day	Average fee per hospital day. Average cost based on various types of hospital diagnosis-related groups and the classification of the disease. We found the average hospital fee was \$1,669 per day.
Lost time costs	C_l	Calculated	Cost of days of lost time
Lost time costs	N_{pl}	Calculated	Number of persons losing time
Lost time costs	N_l	Calculated	Number of lost workdays
Lost time costs	I_l	See Table 10	Incidence of lost time based on the determined risk level for the individual materiel item
Lost time costs	D_{ld}	See Table 11	Factor for the number of lost workdays per person based on historical lost workday distribution
Lost time costs	D_{lt}	See Table 12	Lost time population distribution based on average lost workday distribution
Lost time costs	W_d	\$53.97 per day	Average wage per day. We based the average wage per day (W_d) on the salaries and numbers of persons drawing that salary for a selected group of personnel. We determined an average wage to be \$53.97 per day.
Lost time costs	B_f	1.41	Wage fringe benefit factor. We assigned the fringe benefit factor (B_f) a value of 1.41. It is a standard factor within the government used for programming personnel budget requirements and is representative of other corporate benefit factors.
Disability costs	C_{di}	Calculated	Cost of disabilities

Table 4. Equation Variables (continued)

Disability costs	N_{pd}	Calculated	Number of persons disabled
Disability costs	I_v	See Table 13	Incidence of VA disability based on the determined risk level for the individual item of materiel, equipment, or weapon system
Disability costs	T_v	0.25	VA disability adjustment factor for delayed disability (5 years/20 years)
Disability costs	D_v	See Table 14	VA disability population factor based on historical rate of disability distribution
Disability costs	B_v	See Table 15	VA disability compensation factor per month per rate of disability
Disability costs	I_t	0.001	Incidence of active-duty temporary disability (1 case/1000 persons)
Disability costs	B_t	\$9,242 per person	Active-duty temporary disability compensation per year
Disability costs	I_p	0.011	Incidence of active-duty permanent disability (11 cases/1000 persons)
Disability costs	B_p	\$12,864 per person	Active duty permanent disability compensation per year
Rehabilitation costs	C_r	Calculated	Cost of rehabilitation
Rehabilitation costs	N_r	Calculated	Number of rehabilitation cases
Rehabilitation costs	D_r	See Table 16	Eligible VA disability population factor based on rate of disability distribution equal to or greater than 20 percent
Rehabilitation costs	Q_r	0.05	VA rehabilitation qualification factor (5 cases/100 persons eligible)
Rehabilitation costs	B_r	\$12,000 per year per person	VA rehabilitation benefit per year per person. We estimated to be \$12,000 per year per person. Rehabilitation benefits may vary per person, but we considered \$12,000 to be a reasonable estimate. Other benefits may be available for eligible disabled persons, but we did not consider these other benefits.
Death costs	C_{de}	Calculated	Cost of death
Death costs	N_{de}	See Table 17	Number of deaths per year
Death costs	B_{de}	\$200,000	Death benefit and expenses

Table 5. Incidence of Illness or Injury (I_i) for System Risk Categories

System risk category	Incidence rate (I_i)
High	0.122
Medium	0.095
Low	0.067

Table 6. Number of Clinic Visits (N_c) for Hazard Severity Categories

Hazard severity category	Number of clinic visits (N_c)
I	5
II	3
III	2
IV	1

Table 7. Incidence of Hospitalization (I_h) for System Risk Categories

System risk category	Hospitalization rate (I_h)
High	0.013
Medium	0.007
Low	0.0005

Table 8.
Factors for Average Number of Days in Hospital (D_{hd}) (days/person)

Length of stay in hospital	Factor (D_{hd})
<2 days	1.0
2–5 days	3.5
6–30 days	18.0
>30 days	30.0

Table 9. Factors for Hospitalization Population Distribution (D_{ho}) by Length of Stay in Hospital for System Risk Categories

System risk category	Length of stay in hospital			
	<2 days	2–5 days	6–30 days	>30 days
High	0.40	0.35	0.17	0.08
Medium	0.40	0.36	0.18	0.06
Low	0.42	0.37	0.20	0.02

Table 10. Incidence of Lost Time (I_l) for System Risk Categories

System risk category	Lost time rate (I_l)
High	0.055
Medium	0.054
Low	0.028

Table 11.
Factors for Average Number of Days of Lost Time (D_{ld}) (days/person)

Number days of lost time	Factor (D_{ld})
<2 days	1.0
2–5 days	3.5
6–30 days	18.0
>30 days	30.0

Table 12. Factors for Lost Time Population Distribution (D_{lt}) by Days of Lost Time for System Risk Categories

System risk category	Lost time			
	<2 days	2–5 days	6–30 days	>30 days
High	0.22	0.30	0.29	0.20
Medium	0.20	0.33	0.31	0.16
Low	0.15	0.43	0.38	0.04

Table 13. Incidence of VA Disability (I_v) for System Risk Categories

System risk category	VA disability factor (I_v)
High	0.032
Medium	0.012
Low	0.00005

Table 14. Factors for Disability Population Distribution (D_v) by Degree of Disability for System Risk Categories

System risk category	Degree of disability			
	10%	20%–50%	60%–90%	100%
High	0.44	0.42	0.10	0.04
Medium	0.44	0.44	0.09	0.03
Low	0.43	0.48	0.08	0.01

from the historical data. We assigned an appropriate incidence of hospitalization to the system categories, just as we did with the incidence of illness and injury. The high- and low-risk category values represent the medium (mean) risk category value plus or minus one standard deviation respectively. The values are listed in Table 7.

We based the factor for the average number of days in the hospital (D_{hd}) on historical hospital length-of-stay data. This approach provides for a future capability to discriminate between hospital stay

"The primary sources for our lost time data are from the Bureau of Labor Statistics."

times (bed days), and correlates directly with the hospitalization population distribution. For this

model component, we determined numerical factors for the four categories of days in the hospital. The category values represent the midpoints of the range of days in each category. The exception is the greater than 30-day category. Because the historical data available only listed the bed days as greater than 30 days, we selected a conservative value of 30 days for this category. The values are listed in Table 8.

We based the factor for the hospitalization population distribution (D_{ho}) on historical data for the percentage of persons hospitalized for four selected hospital length-of-stay distribution categories. This distribution approach, when combined with the factor for the average number of days in the hospital, provides a future capability to discriminate between hospital length of stay categories. For this model component we determined numerical values for the four hospitalization population

distribution factors within each risk category based on the historical data. The high- and low-risk category factors within each length of stay category represent normalized values of the medium (mean) values plus or minus one standard deviation. The system risk categories with their distribution factors are listed in Table 9.

Lost time costs (C_l). The primary sources for our lost time data are from the Bureau of Labor Statistics. These included *Results of Labor Statistics Survey on U.S. Occupational Injuries, Illnesses in 1993* and tabular data on the percentage distribution of nonfatal occupational injuries and illnesses involving days away from work for 1992.

We correlated selected Department of Labor illness or injury categories with the categories of health hazards. We considered the data representative of the range of lost time rates within the Army for hazards associated with materiel systems. We then selected incidence of lost time rates (I_l) from the historical data and the three industry categories previously discussed. We assigned the selected incidence of lost time rates to the system categories, just as we did with the incidence rates for illness and injury and of hospitalization. These values are listed in Table 10.

We based the factor for the average number of days of lost time (D_{ld}) on historical distribution data for lost workdays. This approach provides a future capability to discriminate between selected lost day categories and correlates directly with the lost time population distribution. For this model component we determined numerical values for the four categories of lost time. These factors were determined in the same manner as the hospital factors. The values are listed in Table 11.

We based the factor for lost time population distribution (D_{lt}) on historical data for the percentage of persons losing time for four selected lost workday distribution categories. This distribution approach, when combined with the factor for the average number of days of lost time, provides for a future capability to discriminate between lost workday categories. For this model component, we determined numerical values for the four lost time population distribution factors based on historical data. The high- and low-risk categories within each length of lost time category represent the normalized values of the medium (mean) values plus or minus one standard deviation. The values are listed in Table 12.

Disability costs (C_{di}). The primary source for our VA disability data was the Department of Veterans Affairs, National Center for Veteran Analysis and Statistics, Demographics Division. A report by the Armed Forces Epidemiological Board Injury Prevention and Control Work Group provided information on active-duty temporary and permanent disability.

Disability costs (C_{di}) consist of costs for delayed VA disability and more immediate active-duty disability. Active-duty disability is either temporary or permanent.

We selected the incidence of VA disability (I_v) from reports by the National Center for Veteran Analysis and Statistics involving disability compensation by class of major disability by combined degree. The data were current as of March 1995. We correlated selected classification of illness or injury diagnoses with the categories of health hazards. We considered these data representative of the range of disability rates within the Army for hazards associated with weapon systems. We

then calculated incidence of disability rates from the historical Persian Gulf disability data. The high- and low-risk category levels represent the medium (mean) value plus or minus one standard deviation. Because the value for the low-risk value was a negative number, we selected the range minimum value for the low-risk category. We assigned an appropriate incidence of disability to the system categories, just as we did with the incidence of illness and injury. The values are listed in Table 13.

We selected incidence of active-duty temporary disability (I_t) and incidence of active-duty permanent disability (I_p) from a report by the Armed Forces Epidemiological Board Injury Prevention and Control Work Group on illness and injury. Its report provided basic information on active-duty

"The primary source for our VA disability data was the Department of Veterans Affairs, National Center for Veteran Analysis and Statistics, Demographics Division."

temporary and permanent disability compensation. We calculated a temporary disability incidence rate of 1 case per 1,000 persons. This equates to an factor of 0.001. For permanent disability, we calculated an incidence rate of 11 cases per 1,000 persons for a factor of 0.011. We calculated single rates only because of the limited data presented in the report.

The VA disability adjustment factor (T_v) reduces the VA disability population. Eligible veterans may receive VA disability after leaving military service. One would likely see disabilities compensated by the VA only later in the life of a system. We

assumed that for a system with an operational life of 20 years, eligible veterans would receive VA disabilities at 15 years. This means that we would only expect disabilities during the last 5 years of a system's operational life. This correlates to a factor of 0.25 (5 years/20 years).

We based the disability population distribution factor (D_v) on historical data for the percentage of persons disabled for four

"The primary source of our rehabilitation data was the Department of Veterans Affairs fact sheets. We selected the incidence of VA disability (I_v) from the National Center for Veteran Analysis and Statistics database reports."

selected disability distribution categories. VA establishes disability in 10 percent increments. The four categories allow for the future capability to discriminate between categories of disability costs.

Based on the historical data, we assigned a distribution factor for each risk category. The high- and low-risk category levels represent the normalized values of the medium (mean) values plus or minus one standard deviation. These factors are listed in Table 14.

We based the VA disability compensation (B_v) factor on historical data for selected degree of disability categories. The approach, when combined with the VA disability population distribution factor for degree of disability, provides the future capability to discriminate between categories of disability costs. The values are listed in Table 15.

We based the active-duty temporary disability compensation factor (B_t) and the active-duty permanent disability compen-

sation factor (B_p) on 1990 historical compensation costs for permanent and temporary disability in the three military services. Using this data provides the future capability to discriminate between military and VA disability costs. The calculated values, from the historical data, for B_t and B_p respectively are \$9,242 per person and \$12,864 per person.

Rehabilitation costs (C_r). The primary source of our rehabilitation data was the Department of Veterans Affairs fact sheets. We selected the incidence of VA disability (I_v) from the National Center for Veteran Analysis and Statistics database reports. These values are the same as those listed in Table 13.

As previously discussed, the VA disability adjustment factor (T_v) reduces the VA disability population. Eligible veterans receive VA disability after leaving military service. We calculated a value of 0.25 (5 years/20 years).

We selected the factor for the eligible VA disability population distribution (D_r) based on historical data for the percentage of persons disabled for three selected disability distribution categories. The values in Table 16 are the same as those listed in Table 14 with the exception of the 10 percent category. Eligibility for rehabilitation is limited to people with a disability of 20 percent or more. This distribution approach provides a future capability to discriminate between categories of rehabilitation costs.

We assumed the qualification factor for rehabilitation (Q_r) to be 0.05 (5 cases per 100 persons eligible). We selected this value based on a subjective estimate of the percentage of people who may apply for and be accepted for rehabilitation benefits. The qualification factor selected may be

low; for example, one VA region estimated its acceptance rate for the VA rehabilitation program to be greater than 20 percent. However, we consider the value adequate for use in the MCAM.

Death costs (C_{de}). The primary source of death data was a report by the Armed Forces Epidemiological Board Injury Prevention and Control Work Group and the death benefit paid by the Serviceman's Group Life Insurance.

We assumed that a potential for death existed only in the catastrophic hazard severity category. There were limited reliable sources of data. This is an area requiring further research to refine the MCAM. The report by the Armed Forces Epidemiological Board Injury Prevention and Control Work Group showed that overall there was approximately 1 death per 1,000 clinic visits. This number is based on the assumption that if a death were to occur, program managers would take immediate action to eliminate or reduce the hazard. We used the values in Table 17 to estimate number of deaths (N_{de}).

There is great variability in calculating the cost of a person's death. Values presented in the literature have varied from over \$100,000 to over \$1 million. Our cost of death includes costs paid by insurance policies plus expenses relating to casualty assistance, honor guard, funeral and burial, family, and other related expenses. Serviceman's Group Life Insurance can pay a beneficiary up to \$200,000 for the death of a soldier. Other expenses incurred by the Army can be substantial. As previously discussed, we did not consider training and personnel replacement costs.

RESULTS

We developed a framework and equations with appropriate variables for estimating reasonable costs for unabated health hazards in Army materiel. We developed reasonable cost estimates by quantifying medical costs associated with unabated materiel system health hazards. The model's lost time component identifies personnel time away from the job, an output directly relating to unit readiness and productivity.

AN EXAMPLE COST ESTIMATION

As an example, we estimated costs for an Army system (System X) evaluated by health hazard assessors, for which they wrote a health hazard assessment report. Remember that health hazards are inherent in all U.S. Army materiel systems. If ignored, however, these hazards can cause serious injuries and illnesses to military and civilian operators throughout the life of the system.

In our case, the medical costs for treating those injuries and illnesses can pose significant financial burdens to the Army and Veterans Affairs

"There is great variability in calculating the cost of a person's death. Values presented in the literature have varied from over \$100,000 to over \$1 million."

health care systems. For example, implementation of recommendations to control health hazards for our example results in avoiding potential medical and lost time costs greater than \$345 million over the life of the system.

System X had 10 health hazards: weapons combustion products, fire extinguish-

Table 15. VA Disability Compensation Factors (B_v) by Degree of Disability (dollars/month/person)

Degree of disability	VA disability compensation factor (B_v)
10%	\$91.00
20%–50%	\$340.25
60%–90%	\$915.50
100%	\$1,865.00

Table 16. Eligible VA Disability Population Distribution Factors (D_v) by Degree of Disability for System Risk Categories

System risk category	Degree of disability			
	10%	20%–50%	60%–90%	100%
High	0.0	0.42	0.10	0.04
Medium	0.0	0.44	0.09	0.03
Low	0.0	0.48	0.08	0.01

Table 17. Number of Deaths (N_{de}) for Hazard Severity Categories

Hazard severity category	Number of deaths (N_{de})
I	1
II	0
III	0
IV	0

Table 18. Health Hazards and Associated Risk Indices for System X

Hazard category	Hazard	Risk assessment code (RAC)	Hazard severity category	Hazard probability
Chemical substances	Weapons combustion products	1	I	A
Chemical substances	Fire extinguishing agents	2	II	C
Chemical substances	Carbon dioxide	3	II	D
Acoustical energy	Impulse noise	2	II	C
Acoustical energy	Steady-state noise	2	II	C
Temperature extremes	Cold stress	2	II	C
Temperature extremes	Heat stress	2	II	C
Oxygen deficiency	Oxygen deficiency (ventilation)	2	II	C
Radiation energy	Nonionizing radiation	2	II	C
Radiation energy	Ionizing radiation	4	II	E

Table 19.
Life-Cycle Costs of Several Unabated Health Hazards for System X

Hazards	Costs (Thousands of Dollars)						
	Clinic	Hospital	Lost time	Disability	Rehabilitation	Death	Total
Weapons combustion products	88,402	81,904	27,852	98,173	1,432	4,000	301,763
Nonionizing radiation	1,612	1,820	619	2,182	32	0	6,265
Carbon dioxide	81	91	31	109	2	0	314
Ionizing radiation	8	9	3	11	0	0	31
Six other hazards	9,672	10,920	3,714	13,092	192	0	37,590
Total	99,800	94,700	32,200	113,600	1,700	4,000	346,000
Note: Table totals are rounded to the nearest hundred thousand.							

Table 20. Individual Component Outputs for Selected Hazards for System X—Yearly Basis

Hazard	Component outputs								
	Clinic visits	Persons injured/ill	Persons hospitalized	Hospital days	Persons losing time	Lost work-days	Persons disabled	Rehabilitation cases	Deaths
Weapons combustion products	36,230	3,250	346	2,454	1,465	18,300	533	7	1
Nonionizing radiation	661	72	8	55	33	407	12	0	0
Carbon dioxide	33	4	0	3	2	20	1	0	0
Ionizing radiation	3	0	0	0	0	2	0	0	0
Six other hazards	3,966	432	48	330	198	2,442	72	0	0
Total	40,900	3,800	400	2,800	1,700	21,200	600	7	1
Note: Table totals are rounded.									

ing agents, carbon dioxide, impulse noise, steady-state noise, cold stress, heat stress, oxygen deficiency (ventilation), nonionizing radiation, and ionizing radiation. Table 18 lists the identified health hazards and the risk assessment codes assigned by the health hazard assessors during their evaluation.

We determined the costs incurred over the operational life (20 years) of the system as a result of unabated health hazards. These costs are significant—in this case, greater than \$345 million. Lost time, disability, rehabilitation, and death costs of \$150 million, along with clinic and hos-

"The medical cost data clearly showed that unabated health hazards can have a significant impact on readiness and the health care system over the operational life of our system."

pitalization costs of \$195 million, impact military readiness, productivity and the health care system. Table 19 summarizes the model component life-cycle costs for several

of the 10 unabated health hazards for the system. We calculated costs for one hazard in each risk category. Health hazard intervention can reduce these costs. The application of dollar amounts to the health hazards provides new insight into areas requiring attention concerning materiel acquisition decision making.

Program managers can easily see which health hazards require immediate attention and priority abatement. They can determine whether the magnitude of the costs could have a severe impact on readiness. The avoidance of these costs can make resources available for other use—an im-

portant consideration in our current cost-constrained environment.

The medical cost data clearly showed that unabated health hazards can have a significant impact on readiness and the health care system over the operational life of our system. The individual component outputs give a detailed picture of these impacts. Table 20 summarizes the yearly individual component output data for several of the 10 unabated health hazards. Again, we calculated output data for one hazard in each risk category.

If these hazards are not abated, we can expect to see 3,800 injured or ill soldiers, 1,700 soldiers losing time at work, 600 disabled soldiers, and 400 hospitalized soldiers on a yearly basis. This has a tremendous impact on available manpower. Lost workdays account for a total of 21,200 days per year. Yearly, we can expect 40,900 clinic visits and 2,800 hospital days as a result of exposure to health hazards resulting in illness and injury. This also presents a great burden on the health care system. Health hazard intervention can reduce these costs.

EVALUATION OF MODEL

We assessed the results of the medical cost avoidance model from the perspectives of validity (Did we measure the right things?), reliability (How well can we measure those things?), practicality (Can we make a decision based on the model output?), and sensitivity (What is the impact of the model output to possible errors in the data?). Validity and reliability are relative measures, not absolute. For all of these perspectives, improvements in data collection and source data will improve the MCAM's validity.

VALIDITY

As a first step, the model produces reasonable “real world” results. The components of this model are representative of the basic outcomes that all prevention programs should measure. Most of the data for the model parameters are obtained from actuarial-type databases. While we linked industry categories to Army system categories so that we could use hazard data available for industry, rather than using actual Army data, this substitution does not invalidate the model. Existing Army and industry-wide databases do not relate illnesses and injuries to their “root cause.” The degree of validity of the model may increase with the exclusive use of Army data. We did not include some potential indirect costs that could be incurred as a result of illness or injury. We do not believe that this detracts from the utility of the model. For example, some of these costs could include: the costs to acquire and train personnel replacements for those soldiers injured, ill, or killed, performance degradation costs or the nonmonetary effect on military readiness, and the costs related to the impact on family quality of life.

We recognize that these costs could be substantial and should be considered. We also recognize that these costs may vary greatly; for example, it costs more to train a pilot than an infantryman. We believe the system program manager is in the best position to make an assessment of the impact of these additional costs.

RELIABILITY

The MCAM outputs are reliable. Its parameters are measurable or can be estimated. Assuming medical assessors perform risk assessments correctly and con-

sistently, the model will produce the same outputs. Remember that risk assessments are subjective in nature; as assessors become more experienced, then we would expect to see them assign a particular hazard the same hazard severity, hazard probability, and risk assessment code. The data used in this model, while obtained from industry-wide sources, were necessary and adequate to obtain quantitative cost estimates. The data are comprehensive

“The MCAM outputs are reliable. Its parameters are measurable or can be estimated.”

and reliable. Additionally, these sources already have established collection procedures, update their data annually, and make them available for use. Improved reliability could be achieved by having outpatient and/or inpatient medical records provide specific information concerning the “root cause” of an illness or injury. Currently, medical records contain a diagnosis, but do not contain the “root cause.” In the future more detailed statements in medical records would improve data reliability. An example of this kind of useful information is: “This hospital visit for more detailed tests was the result of an exposure to a chemical substance from an armored fighting vehicle. It resulted in a respiratory system disease diagnosis by medical personnel.”

PRACTICALITY

The validity and reliability of the MCAM are adequate for its purpose as an initial cost estimating model. Its outputs are also very practical to use, and help explain what a RAC means for health hazards associated with a particular system.

Greater data specificity for hazard and medical diagnosis should improve the understanding of the monetary impact of different hazards with the same RAC. The accuracy of most of the individual measures could be improved, but doing so would require research funding.

SENSITIVITY

The model is most sensitive to the selection for hazard severity and hazard probability (Table 1). Once the matrix cell has been selected using those two factors, the model exhibits the greatest sensitivity to hospital and clinic costs (Tables 20 and 21). Due to differences in the sizes of both hospitals and clinics, these costs can vary significantly. Trying to obtain the “true” hospital and clinic costs would be highly desirable; however, we have minimized extreme cost variations by averaging historical data for many types of hospital and clinical services.

DISCUSSION

We showed that the MCAM will estimate total costs based on the determination of a health risk; if we can quantify a health risk, then we can estimate its costs. USACHPPM’s Health Hazard Assessment Office is currently testing an automated version of the cost model. We incorporated the model into their health hazard assessment database, and we developed a project officer module for USACHPPM personnel to use in performing health hazard assessments. Thus these estimated costs are being provided to program managers, but we do not know how they are using this information. This issue requires dedicated follow-up, to de-

termine the efficacy of the model’s use and its potential impact.

Using the results of the MCAM can make health risk management more effective. Quantifying health hazard costs improves a program manager’s understanding of the monetary impact of not eliminating or mitigating a health hazard. The model’s lost time component identifies personnel time away from the job, an output that directly relates to unit readiness and productivity.

The model is based on the events (clinic visits, hospitalization, lost time, disability, rehabilitation, and death) that can be triggered by exposure to the causes of disease and injury. It would therefore be useful for assessing similar hazard intervention in other related programs—system safety, human factors engineering, and preventive medicine.

The bottom line for prevention programs is to reduce the personal, personnel, and health care costs of unabated health hazards. To assess the reduction in medical costs, prevention programs can use the model’s component outputs as performance indicators and measures of effectiveness.

OTHER APPLICATIONS

While we developed the MCAM for assessing the health hazards in Army materiel, it has applications that expand into other MANPRINT (Manpower and Personnel Integration) domains that assess health risks.

The model could be used in the following ways:

- System safety engineers and human factors engineers could estimate medical costs for system safety and human

factors engineering hazards of Army materiel.

- Industrial hygienists and occupational health personnel could estimate medical costs for hazards of industrial production line operations.
- Environmental engineers and health risk assessors could estimate medical costs for hazards associated with the cleanup of hazardous waste sites. They could also assess other environmental health hazards from environmental pollution.
- Preventive medicine physicians, environmental science officers, sanitary engineers, and community health nurses could estimate medical outputs for environmental hazards found on the battlefield.

LIMITATIONS OF THE MODEL

There are several limitations to our model:

- We do not include pollution prevention savings in the estimate of medical costs. We consider only potential dollar costs avoided for medical and lost time costs related to the illness or injury caused by exposure to the hazard.
- We do not subtract out the costs of the actual implementation of health hazard assessment recommendations. These costs depend on the type of recommendation made, the degree of reduction of the health hazard, and the life-cycle phase. Costs may include potential publication or labeling, pro-

TECTIVE equipment, production process changes, engineering design, operation and maintenance, retrofitting, and disposal.

- We do not incorporate the costs to acquire and train replacements for personnel injured, ill, or killed. We also do not incorporate the costs of degraded performance or the nonmonetary effect on military readiness. Nor do we incorporate the costs related to the impact on family quality of life. As we previously discussed, these costs could be substantial and can be best addressed by program managers.
- We do not use only military data for estimating costs. In the absence of required relevant military data we extrapolate private industry data and relate them to military systems. We made the assumption that the industry data were relevant and we could develop Army materiel risk categories based on this industry data. We believe the results obtained are reasonable. However, we do encourage readers to research and apply equation variable data appropriate for their particular operation.

We believe that pollution prevention, hazard abatement, and other implementation costs would be minimal compared to system procurement costs, when health hazard assessment recommendations are incorporated during system design.

CONCLUSIONS

The framework we have developed provides a method to quantify reasonable estimates of the medical and lost time costs associated with unabated health hazards associated with Army materiel. Using the outputs of the model would increase the effectiveness of health risk assessment and management.

We have presented the model to stimulate thought and feedback; it can and should be further refined. As its use increases and follow-up data become available, we can develop more accurate cost distribution factors, resulting in more accurate forecasts of health costs.

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